High Speed Stressing and Testing for Dielectric Withstanding Voltage (DWV or Flash) of Multilayer Ceramic Capacitors

A. C. Grossenbacher, Donald Peter, and Jeff Williams

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Electro Scientific Industries, Inc., 13900 N.W. Science Park Drive, Portland, Oregon 97229-5497, (503) 641-4141, Telex: 474-2064, Fax: (503) 643-4873

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Abstract

A method of high-speed contacting and detecting the flash breakdown characteristics of multilayer capacitors is described. These tests are made with a constant charge current of up to 50 milliamps as prescribed by MIL Standard 39014C.

The total test times can be reduced to approximately 30 milliseconds. The paper describes the following:

1. Discussion of methods used to cause voltage breakdowns in capacitors to occur in less than 30 milliseconds as contrasted with those that take a number of seconds to cause breakdown at the same voltage.
2. Detecting presence of part prior to test to avoid poor test results because of contact problems;
3. Fast operating arc-over detection and over-voltage shut down methods to:
    a. detect short-time duration arc-overs
    b. to protect contact mechanism from over-current and over-voltage damage
4. Testing of part after discharge to detect possible failures during discharge:
5. Characteristics of the voltage supply required for:
    a. uniform and controlled charge currents,
    b. fast voltage slew rates and
    c. fast shutdown (less than one microsecond) to protect the system and contacting mechanism.

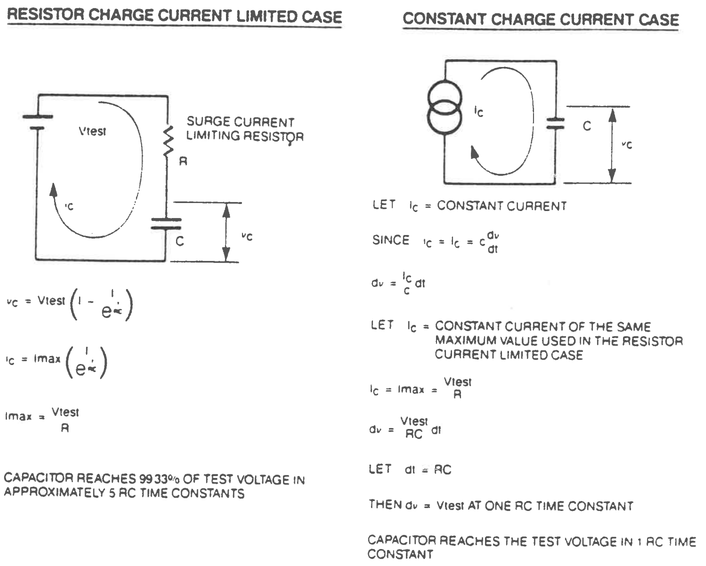
Introduction

This paper describes a dielectric withstanding voltage (DWV or Flash) testing system that uses programmable constant charging and discharging currents. This method is contrasted with the exponentially decaying currents that are typical of resistor charge current limited systems. Calculations and experimental data indicate that a constant current system has the following characteristics:

- The breakdown voltage is arrived at in a much shorter period of time, providing much higher production rates.
- More energy is available to ensure that weak spots will break down, reducing latent failures.
- This higher energy causes failure of marginal parts that would otherwise be passed as good parts and could fail in service.

How Fast Can the Test Voltage be Applied?

The DWV test prescribed by MIL standard 39014C calls for the limiting value of surge current to be between 30-50 milliamperes. Fig. 1 compares the calculation of the voltage rise across a capacitor for the constant current case and for the resistor limited current case, Fig. 2 graphs these two cases. It is clear that the test voltage is attained at least 5 times faster in the constant current case than in the resistor limited case.


RESISTOR CHARGE CURRENT LIMITED CASE
Vtest
SURGE CURRENT LIMITING RESISTOR
R
ic
C
vc
CONSTANT CHARGE CURRENT CASE
Ic
C
vc

$v_c = V_{test}\left(1 - \frac{1}{e^{\alpha}}\right)$

$i_c = I_{max}\left(\frac{1}{e^{\alpha}}\right)$

$I_{max} = \frac{V_{test}}{R}$

CAPACITOR REACHES 99.33% OF TEST VOLTAGE IN APPROXIMATELY 5 RC TIME CONSTANTS

LET I_c = CONSTANT CURRENT

SINCE $i_c = I_c = C\frac{dv}{dt}$

$dv = \frac{I_c}{C}dt$

LET I_c = CONSTANT CURRENT OF THE SAME MAXIMUM VALUE USED IN THE RESISTOR CURRENT LIMITED CASE

$I_c = I_{max} = \frac{V_{test}}{R}$

$dv = \frac{V_{test}}{RC}dt$

LET $dt = RC$

THEN $dv = V_{test}$ AT ONE RC TIME CONSTANT

CAPACITOR REACHES THE TEST VOLTAGE IN 1 RC TIME CONSTANT

FIG. 1 CALCULATIONS OF VOLTAGE RISE ACROSS CAPACITOR BEING TESTED

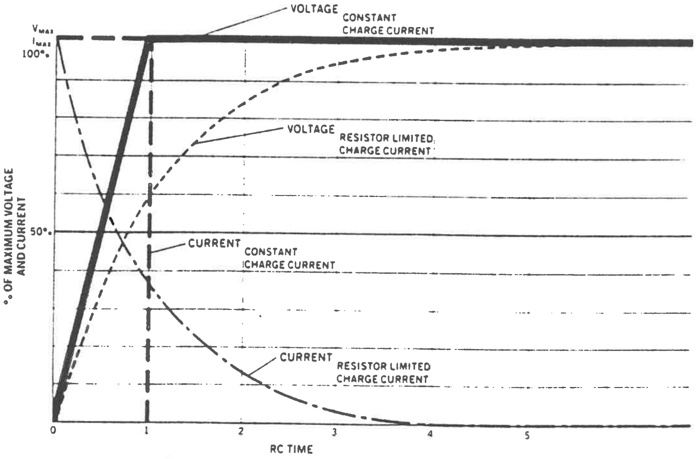


FIG. 2 GRAPH OF CAPACITOR VOLTAGE AND CURRENT

These results are graphed in Fig. 5. The total energy is the area under the curves and is the same for each case at any given charge voltage. It is obvious however that the area accumulating under curve 5 is much more rapid than that under curve 6.

Is This Faster Accumulation of Energy a Benefit?

If there is a resistive flaw or thin section in the dielectric, it is desirable to detect it as soon as possible. If the flaw is marginal and not detected, it could develop into a more serious leakage pathway at a later time.

This faster charging with higher instantaneous peak power means a more stringent flash test for detecting marginal capacitors than with traditional resistor-limited charging methods.

Application

What do these calculations have to do with a real capacitor such as shown in Fig. 6?

Fault #1 is a leakage path with high resistance that will eventually decompose or burn into a lower resistive carbonized track (arc-over or flash). This will occur when the energy it consumes or the power it dissipates over time heats it up enough for this to occur. Fault #2 will become the same kind of fault as 1 as soon as the voltage has risen high enough to arc across the small distances between the plates and the flaw. Preceding arguments indicate that both of these faults will break down *much faster* under constant current because of:

- The faster rise in breakdown voltage.
- The much higher energy (or power at any given time) to initiate the breakdown.
- The higher energy that causes marginal units, which might have ordinarily been passed as good units, to be heated and destroyed.

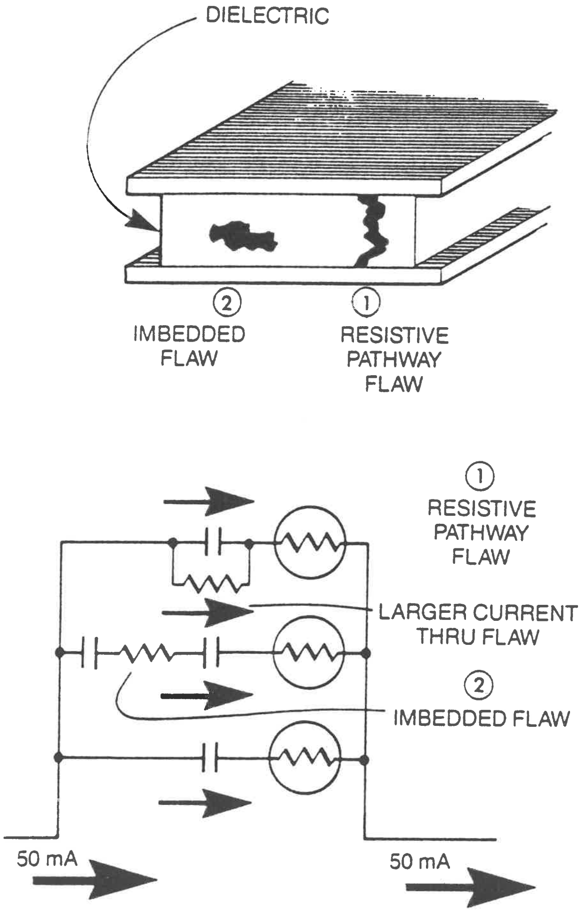


FIG. 6 TYPICAL REAL MULTI LAYER CAPACITOR

Actual Tests

Tests of three groups of different values and styles of capacitors were made in an attempt to verify the theoretical assumptions made to this point. The population of each group was 50 units.

All the groups were good capacitors with no rejects so the tests had to be made at a voltage that would break them all down.

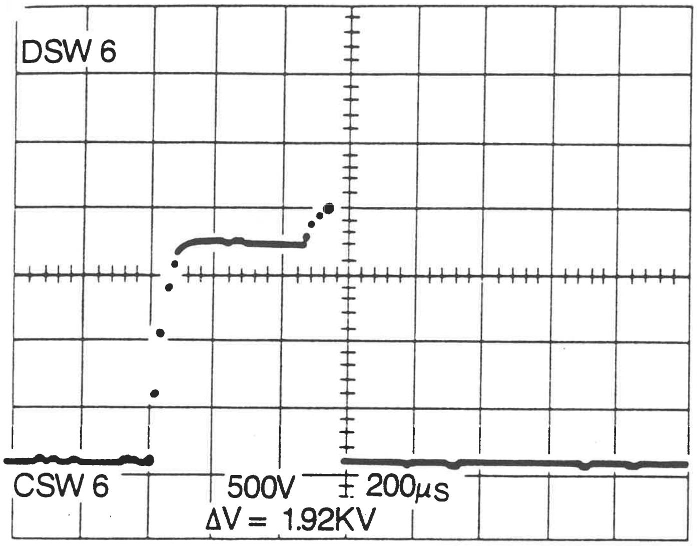
The tests were made by limiting the charging currents to 1mA and finding the typical breakdown voltage for the different types being tested. The units were then tested with a voltage in excess of the average breakdown value, but at increased charging current levels.

The groups tested are tabulated in Fig. 7 and the test results are in Fig. 8.

GROUND NUMBER	CAPACITOR VALVE AND RATED VOLTAGE	DIELECTRIC TYPE AND THICKNESS	TESTED BREAK DOWN VOLTAGE MIN MAX	BREAK DOWN TIMES AT DIFFERENT CURRENTS		
				1 ma	40 ma	400 ma
1	1 MFD 100V	X7R .00091 inch	400 - 800	1-2 sec.	10 ms	<3ms
2	0 1 MFD 100V	X7R .0012 inch	600 - 1000	*	<1.5 ms	
3	0.01 MFD 100V	COG .00125 inch	1900 - Power Supply Limit of 2000	*	*	<0.6 ms

*THESE TESTS COULD NOT ACHIEVE BREAKDOWN AT THE MAX OF 2000 AVAILABLE VOLTS

FIG. 7 DATA FROM CAPACITOR TESTS



0.01µF TESTED WITH 400mA
BREAKDOWN TIME Δt = <0.6 ms

Group 1—(1µF) The time for breakdown decreased from 1-2 seconds to 10 milliseconds when the charge current was increased from 1mA to 40mA.

Group 2—(0.1µF) These units did not break down at 1mA charge current even though the voltage was at the maximum available of 2000 volts. They did break down within 1.5 milliseconds when the current was raised to 40mA.

Group 3—(0.01µF) These units did not break down at the maximum available voltage of 2000V with currents of 1mA or 40mA. They did break down very rapidly in less than 0.6 milliseconds when the test current was raised to 400mA.

Physical Examination

Some of each group were cut open after breakdown and examined for visual damage. The units that broke down faster at the higher current levels exhibited the same evidence of burning and violent destruction as did the units which had less current applied to them but had the test voltage applied for a longer period of time (longer soak time). This evidence supports the theory that defects in capacitors can be found by applying a larger current over a shorter period of time.

A Practical System

Using constant current as a test requires careful design to prevent damage to the electronics and contacting system. Fig. 9 shows a test voltage current versus time diagram for a practical test system. The results tabulated in Fig. 7 show that this complete test cycle can be done in less than 30 milliseconds for most values of multilayer ceramic capacitors.

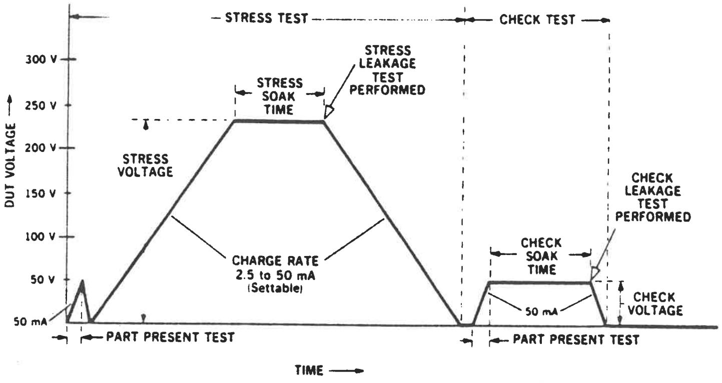


FIG. 9 TEST CYCLE PROFILE OF
A PRACTICAL DWV TEST SYSTEM

Contacts

If high resistance contact is made to a part (or no contact at all) the constant current flowing could generate an energy high enough to seriously burn the contacts. This can be avoided by raising the test voltage to a low voltage (50V) and testing for a charging current, indicating that the capacitor under test has been contacted (see Fig. 9). The absence of or low value of a charging current indicates that the contact has either not been made or is of high resistance. If the voltage is allowed to rise, most of the energy would be dissipated in the defective contact which could cause serious burning and pitting. The test must be aborted before this damage occurs.

High Speed Current Shutdown

The units being tested can be expected to break down at any time. This condition is detectable by monitoring the voltage buildup. Any time the voltage diminishes from its present value (unless directed to do so) is an indication of a fault forming in the unit under test. Because of the high levels of energy involved, the test must be aborted and the test voltage must be turned off as fast as possible. Design goals should be approximately 1 microsecond shut down times to protect the system and contacting mechanisms.